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BURNING IN PINYON-JUNIPER WOODLANDS

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BURNING IN PINYON-JUNIPER WOODLANDS

INTRODUCTION

Pinyon-juniper woodlands occupy between 25 and 32 million ha in the western United States (Arnold et al. 1964, Clapp 1936, Kuchler 1964,) and more than 5.7 million ha in Arizona and New Mexico (Springfield, 1976). Pinyon-juniper woodlands in Arizona and New Mexico are located at elevations from 1300 to 2300 m. These woodlands are characterized by a mosaic of pinyon and juniper trees surrounded by interspaces, occupied by varying densities of herbaceous and shrubby vegetation. The principal tree species are: pinyon pine (Pinus edulis¹), Mexican pinyon (P. cembroides Zucc.), Utah juniper (Juniperus osteosperma), one-seed juniper (J. monosperma), alligator juniper (J. deppeana) and Rocky Mountain juniper (J. scopulorum). The dominant understory species in southwestern pinyon-juniper is blue grama [Bouteloua gracilis (H.B. K.) Lag.] although other herbaceous and shrubby plants may be present (Pieper 1977, Springfield 1976). These pinyon-juniper woodlands occur in the transition zone between semiarid vegetation (i.e., chaparral, desert shrub or grasslands) and ponderosa pine forests.

Pinyon-juniper stands vary widely in structure and species composition and occupy soils derived from a broad range of parent materials including granite, basalt, cinders, limestone, sandstone, and mixed alluvium (Aldon and Brown 1971). Soils vary in texture from stony, cobbly and gravelly sandy loams to clay loams and clay, and vary in depth from shallow to deep (Springfield 1976, Pieper 1977). Little is known about the impact of disturbance on nitrogen relations in pinyon-juniper soils.

Wildfires were common in pinyon-juniper type before European settlement (Leopold 1924) and probably restricted the establishment of pinyon-juniper woodlands in savannas to isolated stands of trees occupying shallow, rocky soils which would not support grasses (Burkhardt and Tisdale 1969, Johnsen 1962). Heavy grazing in the late 1800's and early 1900's eliminated fuel continuity, and this, combined with an active fire suppression policy, decreased fire occurrence throughout this type (Wright et al. 1979). Fire exclusion, coupled with decreased grass competition, may have encouraged tree invasion into former grasslands.

Until recently fire was used in pinyon-juniper woodlands primarily to eradicate pinyon and juniper trees which had invaded the grassy areas. However, with increasing fuelwood harvesting in pinyon-juniper, fire is now being used as a slash disposal

tool as well. Generally, fuelwood harvesting removes all bole material larger than 7.6 cm in diameter. Smaller tree materials, stems, and attached leaves are left as slash and either allowed to decompose naturally, or scattered or piled, and burned.

Although some research has been reported on nutrient relationships in pinyon-juniper soils (Barth 1980, Bunderson et al. 1985), few studies have been done on the effect of slash burning on nutrient availability (DeBano et al. 1987, Gifford 1981). Because so little is known about the effect of slash burning on nitrogen dynamics in pinyon-juniper, the following study was conducted to: (1) determine the immediate effects of slash burning on mineral nitrogen in pinyon-juniper soils, and (2) to develop time response functions describing changes in mineral nitrogen over time following fire.

METHODS

Our research design (Figure 1) consisted of a combination of an historical (time sequence) approach for estimating long term responses and an experimental approach for estimating immediate, short term effects to slash burning.

Time Sequence Study

For the time sequence study we established paired plots (one burned and one unburned) in areas which had been partially harvested and the slash piled and burned. Time since burning

was 1-yr (Canary Tank Draw), 2-yr (Jewett), 5-yr (Santa Rita), 20-yr (KV Line), and 25-yr (Cosnino). There were five replicated, paired plots for each age. We resampled the 1-, 2-, and 5-yr plots one year later, which yielded data for plots 2-, 3-, and 6-yr after burning. Because analysis of the first year's data indicated that the N response was concentrated in the first several years after burning (see Results), we did not resample the 20- and 25-yr plots.

Experimental Study

For this part of the study we utilized a classical pre- and post-treatment experiment (Figure 1). We established five paired plots (one as an unburned, control and the other as a burn) in an area which had been harvested for fuelwood the previous year. We measured soil $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ before burning, immediately after burning (within 24 hr), and 1 year after burning. Burning conditions are presented in Table 1.

Study Area

The study area is near Winona, Arizona, approximately 24 km east of Flagstaff, T21N-R9E, T20N-R9E, and T21N-R10E Gila and Salt River baseline and meridian. The soil is a Lithic Ustorthent (George Robertson, soil scientist, USDA Forest Service, Coconino National Forest, Flagstaff, Arizona, personal communication), a gravelly to cobbly calcareous loam, 15-25 cm deep to a hard fractured limestone bedrock. The study plots had

slopes of less than 5 percent. Mean annual temperature is 7° C and average annual precipitation is 40 cm, with summer drought occurring in late May through early July.

The dominant tree species in the study area is Juniperus monosperma, with scattered J. osteosperma and P. edulis. Understory vegetation is dominated by grasses including B. gracilis, Sitanion hystrix, and Sporobolus spp., half shrubs such as Gutierrezia sarothrae, and shrubs such as Chrysothamnus nauseosus and Cowania neomexicana. On sites with severe physical disturbance, Russian thistle (Salsoa kali) is common. In addition to cattle, other dominant herbivores include pronghorn antelope (Antilocarpa americana), mule deer (Odocoileus hemionus) elk (Cervus elaphus), jack rabbits (Lepus spp.), cottontail rabbits (Sylvilagus nuttallii), and various rodents.

Soil Sampling and Analysis

Soils were sampled from 3 depths, 0-2.5 cm, 2.5-10 cm, and 10-25 cm, using a 2.5-cm soil sampling tube. For each plot, 12 soil samples were combined to produce one composite sample for each plot. Since the main rooting zone was within the 2.5-10 cm depth and to save in analytical costs, we focused our chemical analyses on that depth for the time sequence study. For the experimental study we analyzed samples from all depths.

Soils were extracted immediately in the field to prevent post-sampling changes in N concentrations. The composite samples were sieved and split into three subsamples for subsequent

analyses. One 10-20 g subsample was extracted in the field for inorganic N, one was added to a moisture tin for determining moisture content, and one was placed in a paper bag for total organic N analysis. Immediately after sieving, a 10-20 g subsample for analysis of N as ammonium ($\text{NH}_4\text{-N}$) and N in nitrate ($\text{NO}_3\text{-N}$) was added to a pre-weighed 125-ml polyethylene bottle containing 100 ml of 2 N KCl (acidified with HCl to pH = 2.5). The extractant contained 1 ppm phenyl mercuric acetate to halt microbial activity. Samples were refrigerated ($2\text{-}5^\circ\text{C}$) and analyzed colorimetrically within 2-3 days of collection.

Since the bottles plus the extractant had been pre-weighed, the field weight of the extracted soils could be determined by difference. Oven dry weight was calculated using moisture content data from the soil moisture tins.

Ammonium-N and $\text{NO}_3\text{-N}$ were determined colorimetrically on the KCl extract using the Technicon AutoAnalyzer. Methods for ammonium and nitrate were Technicon Industrial Method No. 98-70W/A and 100-70/W, respectively (Anonymous 1974). For total N, 1-2 g of air-dried soil was digested using the selenium-catalyzed, sulfuric acid, hydrogen peroxide, lithium sulfate technique of Parkinson and Allen (1975). The digest was then analyzed using the AutoAnalyzer. All data are presented in terms of elemental N (e.g., as ammonium-N and nitrate-N).

Statistical Analysis

All statistical analyses were performed using the BMDP

statistical package (Dixon 1985). Since a variety of statistical techniques was used, individual techniques used will be presented as the results are presented.

RESULTS

Preliminary analysis of the data using Levene's test for variances (BMDP7D) indicated that variances were not homogenous. Therefore, to better approximate homogeneity of variances all subsequent statistical analyses were conducted on natural logarithmic transformed data.

Time Sequence Study

To determine whether the 5 members of the time sequence could be assumed to be homologous, we compared $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ concentrations among the unburned, controls using the Bonferroni t -test ($p = .05$), in BMDP7D. There were no significant differences among the sites for either $\text{NH}_4\text{-N}$ or $\text{NO}_3\text{-N}$ (Table 2). Thus, we concluded this time sequence was valid (i.e., that the major differences among the sites in $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ of the burned plots is due to time since burning).

The responses of $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ to time since burning differ. The highest $\text{NH}_4\text{-N}$ concentration, 102 mg/kg, was found in the 1 year old plots, with what appears to be an exponential decline in concentration over time (Table 3). Using Bonferroni t -tests, there are no significant differences after year 5.

Nitrate-N appears to lag behind $\text{NH}_4\text{-N}$, with the highest concentration in year 2 (Table 3). Again, there were no significant differences after year 5.

To accomplish our second objective, the development of time response functions, we used BMDP3R to fit least squares, nonlinear regression lines to the data. For $\text{NH}_4\text{-N}$ we fitted the following function:

$$Y = AX^B + E \quad (1)$$

Where Y is $\text{NH}_4\text{-N}$ concentration (mg/kg), X is time (yr) since burning, and A, B, and E are regression coefficients. When A and E are positive and B is negative, this function describes a curve which decreases exponentially and is asymptotic to control values. The coefficient E is the regression fitted asymptote. The resulting function is presented in Figure 2. Residual mean squares for this regression are 375.8, with a standard error of the estimate of 19.39.

For $\text{NO}_3\text{-N}$ we fitted the following function:

$$Y = AX^B e^{C(X^D)} + E \quad (2)$$

Where Y is $\text{NO}_3\text{-N}$ concentration (mg/kg), X is time since burning (yr), and A, B, C, D, and E are regression coefficients. Again, E is the regression fitted asymptote. This function is also plotted in Figure 2. The regression had a residual mean square of 29.20, with a standard error of the estimate of 5.40.

Total N in the soil was greater in the burned plots than in the adjacent controls for the 1-5 year old burned plots (Table

4). However, data are insufficient for satisfactory development of a time response function for this variable.

Experimental Study

Results from the experimentally burned slash piles are presented in Table 5. Slash burning caused immediate (within 24 hr post-burn) increases (significant at 0.05 using BMDP2V, repeated measures analysis of variance) in soil $\text{NH}_4\text{-N}$ for all depths. The response declined with depth. Ammonium-N concentrations were approximately 12 times higher at 0-2.5 cm, 6 times higher at 2.5-10 cm, and 3 times higher at depths greater than 10 cm immediately after burning. Burning caused no immediate changes in $\text{NO}_3\text{-N}$ concentrations.

One year after burning, $\text{NH}_4\text{-N}$ concentrations appear to have declined somewhat in the 0-2.5 cm depth on unburned plots (Table 5); in contrast, concentrations in the 2.5-10 cm and >10 cm depths increased. The most striking change one year after burning was for $\text{NO}_3\text{-N}$. Similar to the pattern for $\text{NH}_4\text{-N}$, the highest concentration (7 times control values) was in the 0-2.5 cm depth, while the 2.5-10 cm depth was 5 times controls and the >10 cm depth was 4 times controls. These differences were significant at 0.05 using the Bonferroni t-test.

DISCUSSION

The results from this study suggested both physical and biological mechanisms were responsible producing mineral

nitrogen following fire. The elevated levels of $\text{NH}_4\text{-N}$ immediately following burning (Table 5) were most likely caused by a physical pyrolysis of litter and surface organic matter which immediately released $\text{NH}_4\text{-N}$. The $\text{NH}_4\text{-N}$ could have originated from the thermal decomposition of amino acids which can occur at 200°C in the presence of colloidal material (Juste and Dureau 1967). These increases in $\text{NH}_4\text{-N}$ immediately following fire are consistent with those reported by other authors for chaparral (DeBano et al. 1979, Christensen 1973), pinyon-juniper (DeBano et al. 1987), and ponderosa pine forests (Ryan and Covington 1986, Mroz et al. 1980). Although, $\text{NO}_3\text{-N}$ was unchanged immediately after the fire, it began to increase significantly shortly following burning and reached a maximum two years following burning (Fig. 2). The concurrent increase in $\text{NO}_3\text{-N}$ and decrease in $\text{NH}_4\text{-N}$ strongly suggests that nitrification was proceeding rapidly. Some loss of $\text{NH}_4\text{-N}$ may have also occurred by volatilization of NH_3 which has been reported to occur in calcareous soils (Stevenson 1982).

Inorganic N concentrations continued to decline so that after 5 years both $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$ levels returned to prefire levels. The decreasing $\text{NO}_3\text{-N}$ levels between the second and fifth year may have been caused by several mechanisms including microbial immobilization and leaching from the burned sites. Uptake of $\text{NO}_3\text{-N}$ by vegetation probably did not occur because plants had not reinvaded most of the sites burned five years earlier, although there was a substantial plant cover on the

areas surrounding the burned sites (personal observation). We did not encounter plant roots while sampling the 1-3 yr old burned sites; apparently, roots from plants in the adjacent areas had not invaded the 1-5 yr old burned sites. However, there is a possibility that highly mobile NO_3^- ions may have leached laterally through the soil and were absorbed by vegetation occupying nearby unburned areas. At this study site the soil is shallow and lateral flow frequently occurs when the soil becomes saturated, particularly during spring snowmelt.

The results of this study also suggest that significant amounts of $\text{NH}_4\text{-N}$ were moved downward in the soil during the fires and remained elevated for at least one year (Table 5). The movement of $\text{NH}_4\text{-N}$ downward in the soil profile during burning probably occurred because organic matter was volatilized at, or near, the soil surface and was driven downward along temperature gradients until it condensed in the cool underlying soil layers. Steep temperature gradients across the upper soil layers were found responsible for translocating hydrophobic substances and other organic compounds downward in the soil during chaparral fires in California (DeBano et al. 1976).

As was expected, $\text{NH}_4\text{-N}$ concentrations were greater in the surface layers and decreased with depth (Table 5).

The increases we observed in total soil N after burning (Table 4) are consistent with results from slash burning studies in Utah pinyon-juniper (Gifford 1981) as well as in other forest and woodland types (e.g., see Neal et al. 1975, Humphreys

and Craig 1981). However, this should not be interpreted as indicating that total N on the site was increased by burning. Clearly, the levels of inorganic N were increased in the soil by burning, as evidenced by the higher levels of $\text{NH}_4\text{-N}$ immediately following burning and $\text{NO}_3\text{-N}$ by two years after burning (Figure 2). However, during the combustion of slash, large quantities of total N were undoubtedly volatilized and lost upward into the atmosphere. Fuel loading on burned sites in our study was about 40 kg/m^2 (Table 1). If the slash contained about 0.40% nitrogen (DeBano et al. 1987) and 75% of it was consumed during burning, then about 0.12 kg/m^2 of N could have been volatilized. This estimate assumes that the loss of N from fuels was proportional to amount of organic matter combusted, as has been shown by Raison and coworkers (1985). If this slash had been piled on areas having a litter layer (such as under the canopy of harvested trees) the litter would have been partially consumed and additional N volatilized.

MANAGEMENT IMPLICATIONS

Before implementing slash burning following fuelwood harvesting in pinyon-juniper, managers should consider its impact on site nitrogen balance. This study presents the first definitive information on the immediate and longer-term effects (0-25 years) of prescribed slash burning on mineral N in pinyon-juniper soils.

Burning of pinyon-juniper slash increases both inorganic and

total soil N for five years following burning, although the increase in inorganic soil N is restricted to small localized burned areas under slash piles. The increased inorganic N, and other nutrients, should improve soil fertility during the first five year period following fire. However, vegetation may not be able to capitalize on this fertilizer pulse because of the lack of revegetation of these burned sites during the time of increased fertility. Therefore, the benefits arising from the increased fertility may not be realized unless the available nutrients move laterally through the soil into nearby unburned areas where they could benefit the growth of plants occupying these sites. Also it must be kept in mind that although prescribed fire may increase soil N, total ecosystem N is reduced, because much of the N in the slash is volatilized and lost into the atmosphere during burning. Finally, the absence of plant establishment and growth on the burned sites for five years following burning represents a loss of site productivity, although, again, this is confined to small areas under slash piles.

In conclusion, although slash burning undoubtedly causes a net loss in ecosystem N because of volatilization during combustion, some of the slash N is mineralized and transferred immediately to the underlying soil. However, because these burned microsites do not revegetate for several years, whether this increased N affects productivity will depend on movement of the N into adjacent areas where it can be utilized by vegetation.

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FOOTNOTES

¹Nomenclature for plants follows Kearney and Peebles (1964) and for animals follows Lehmkuhl et al. (1983).

Figure 1. Research design flow chart

RESEARCH DESIGN

DOES CONTROLLED BURNING OF PINYON-JUNIPER SLASH ALTER SOIL NITROGEN?

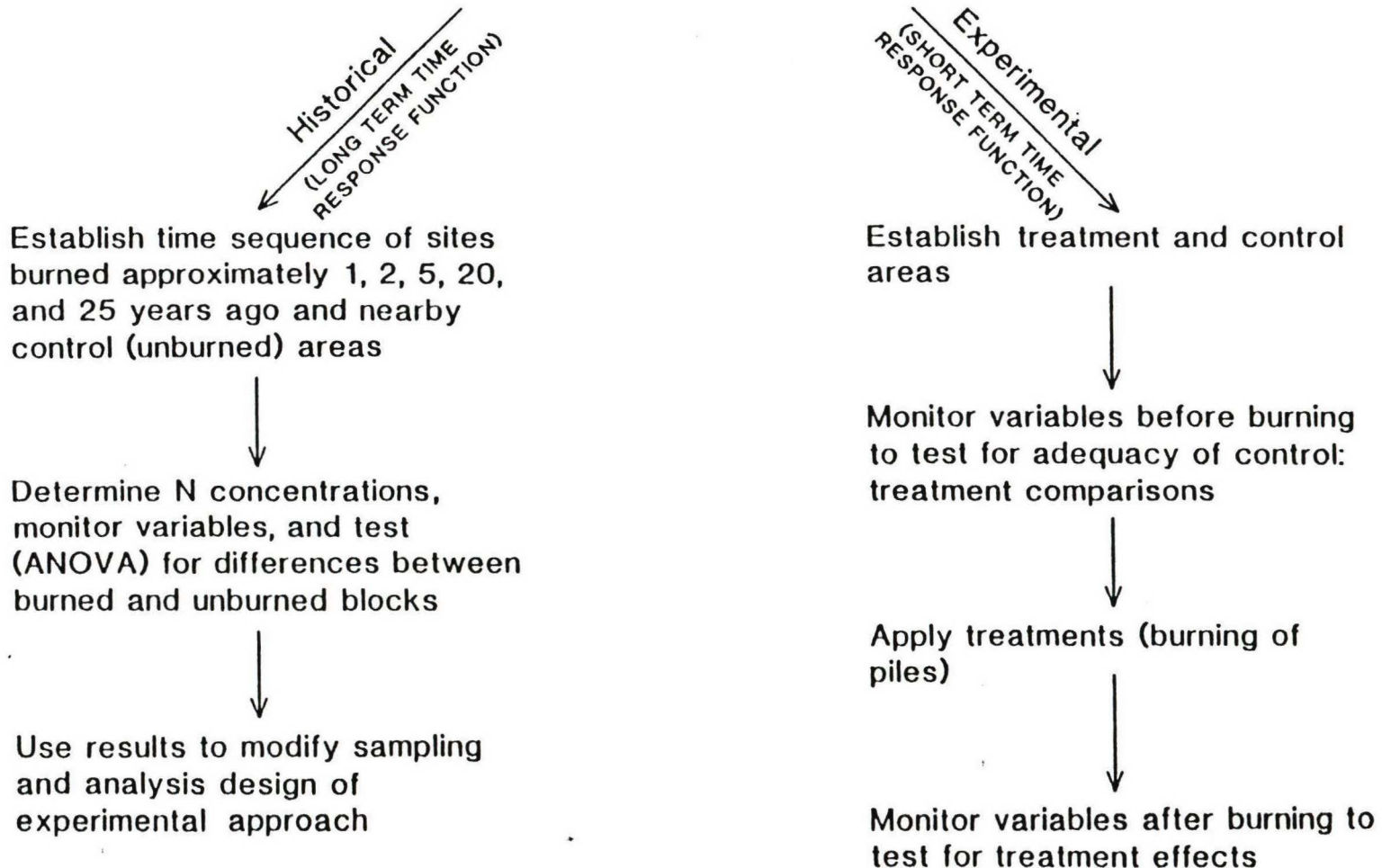


Figure 2. Time response functions for KCL extractable inorganic nitrogen (2.5-10 cm soil depth) following pinyon-juniper slash burning.

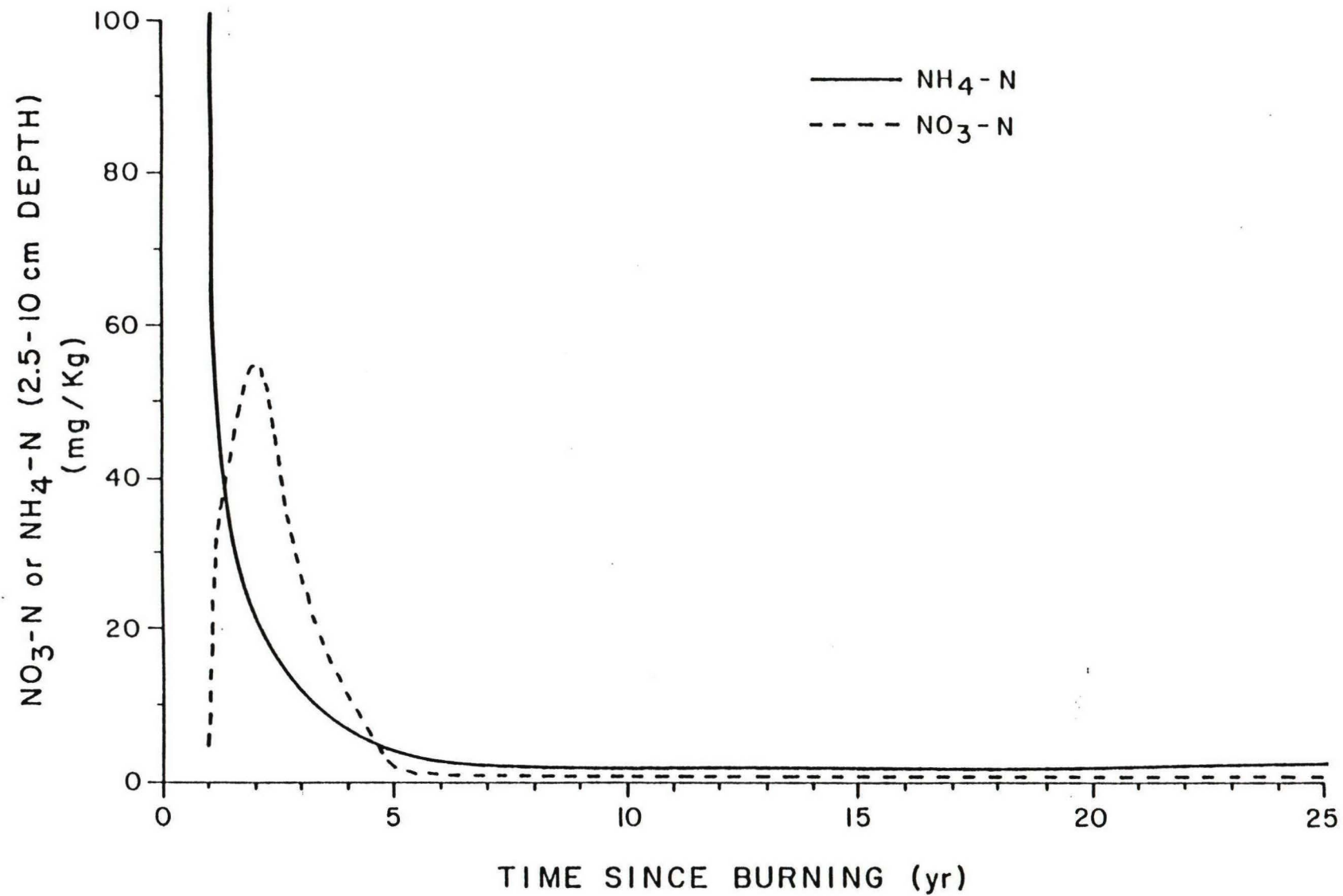


Table 1. Burning conditions for experimentally burned slash piles in a pinyon-juniper woodland.

DATE: October 24, 1985 1100-1400 hrs

AIR TEMPERATURE: 19-23°C

RELATIVE HUMIDITY: 30-24%

FUEL MOISTURE:	Foliage	8.9%
	Twigs <0.25"	10.0%
	Branches 0.25-1.0"	9.1%
	Branches 1.0-3"	9.0%

FUEL LOADS: Piles: 35.8-42.4 kg/m²

Table 2. KCL extractable inorganic nitrogen for control plots for time sequence of slash burning in a pinyon-juniper woodland. (2.5-10 cm soil depth)

Plot Name	NH ₄ -N	NO ₃ -N
	-----mh/kg-----	
Canary Tank Draw	1.62 (0.08)	0.10 (0.021)
Jewett	1.88 (0.07)	0.34 (0.056)
Santa Rita	1.99 (0.16)	0.38 (0.167)
KV Line	1.55 (0.07)	0.26 (0.060)
Cosnino	1.65 (0.09)	0.39 (0.042)

Table 3. KCL extractable inorganic nitrogen for a time sequence of slash burning in a pinyon-juniper woodland. (2.5-10 cm soil depth)

Time Since Burning (yr)	Plot Name	NH ₄ -N	NO ₃ -N
		-----mg/kg-----	-----
1	Canary Tank Draw	102.0 ^a	4.2 ^a
2	Canary Tank Draw	21.4	54.9
2	Jewett	26.1 ^b	20.7 ^b
3	Jewett	8.0	26.5
5	Santa Rita	1.5 ^c	2.5 ^c
6	Santa Rita	2.2	1.7
20	KV Line	2.6 ^c	1.7 ^c
25	Cosnino	0.5 ^c	1.6 ^c

Table 4. Total nitrogen for a time sequence of slash burning in a pinyon-juniper woodland. (2.5-10 cm soil depth)

Time Since Burning	TKN -----mg/kg-----	
	Control	Burn
1 yr	1000	1520
2 yr	1160	1680
5 yr	1010	1420

Table 5. KCl extractable inorganic nitrogen immediately after and one year following burning of pinyon-juniper slash piles.

Depth cm	NH ₄ -N		NO ₃ -N	
	Unburned ¹	Burned	Unburned	Burned
	-----mg/km-----			
Immediately Before and After Burning				
0-2.5	4.9	63.5	8.8	6.9
2.5-10	2.2	15.4	4.7	6.3
>10	1.9	7.2	4.6	4.0
One year Following Burning				
0-2.5	1.3	49.1	5.2	36.3
2.5-10	1.0	20.7	4.1	20.7
>10	0.8	12.3	3.7	15.1

1. The unburned site before and after burning represents the same sample sampling site that was sampled immediately and after burning. The unburned site one year after burning is a control site which was as representative of the burned site before burning as possible.